Dating Alpine brittle deformation with hydrothermal monazite

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Alpine clefts (open fissures) are tectonically formed cm- to meter-sized voids that become filled with hydrothermal fluid. Interaction of cleft-filling fluid with wall rock results in mineral dissolution/precipitation, alteration of the wall rock, and repetitive crystallization of minerals on the cleft walls. Dating monazite from such clefts thus provides a possibility to attribute an age to an exhumation-related brittle structure. Moreover, unlike thermochronometers, the ^{232}Th-^{208}Pb system of monazite is not affected by diffusion and yields a crystallization age.
Two cleft monazites and minerals from the cleft wall have been studied using an electron microprobe at the University of Copenhagen. U-Th-Pb isotope analyses of monazite were subsequently performed on a Cameca IMS1280 SIMS instrument at the Swedish Museum of Natural History (Nordsims facility).

Deformation in the study area located in the Baltschieder Valley, Aar Massif, Switzerland, has been subdivided into three main events: (D1) main thrusting including formation of a new schistosity; (D2) dextral transpression; and (D3) local crenulation including a new schistosity. The two younger deformational structures are related to a subvertically oriented intermediate stress axis, which is characteristic for strike slip deformation. The inferred stress situation is consistent with observed kinematics and the opening of such clefts. Therefore, the investigated monazite-bearing cleft formed at the end of D2 and/or D3, and dextral movements along NNW dipping planes.

The two investigated, millimetre-sized hydrothermal monazites from a late D2 cleft are characterised by high Th/U ratios typical of other hydrothermal monazites. Despite mineralogical changes in the cleft wall, the bulk chemistry of the system remains constant at the decimetre scale. Thus the mineralogical changes require redistribution of elements via a fluid over distances of a few centimetres. ^{232}Th/^{208}Pb monazite ages are not affected by excess Pb and yield growth domain ages between 8.03 ± 0.22 Ma and 6.25 ± 0.60 Ma. These crystallization ages are younger than ^{40}Ar/^{39}Ar ages obtained on white mica from ductile shear zones of the Aar Massif in the Grimsel area and younger than ^{40}Ar/^{39}Ar-dated 13.7 ± 0.1 Ma to 11.0 ± 0.1 Ma old phyllonites (mylonites) outcropping near Baltschieder. Monazite crystallization in brittle structures is in this case coeval or younger than 8 Ma old zircon fission track data, and hence occurred at temperatures below 280°C.

Mesozoic stratigraphy and general structure of the Julian Alps (eastern Southern Alps, NW Slovenia)

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The study area is part of the zone of overlap between the Southern Alps and the Dinarides. This zone is to the north bounded by the Periadriatic Fault and extends south to the South Alpine front, where the Southern Alps are in a direct thrust contact with the

External Dinarides. The Sava Fault, a branch of the Periadriatic fault system, separates the Julian Alps from the South Karavanke Mountains and the Kamnik-Savinja Alps.
The Julian Alps have classically been subdivided into the Tolmin nappes and the overlying Julian nappes. The Tolmin nappes consist of three superposed E-W trending south-vergent nappes. The sediments are typically deeper marine (shale, chert, pelagic limestone, calcareous turbidites) from the Middle Triassic volcano-sedimentary succession up to the Campanian-Maastrichtian flysch. These Mesozoic rocks exhibit a considerable thermal overprint.

The Julian nappes originated from various paleotopographic units that started to differentiate in the Late Carnian. Small scale half-grabens did exist in the Middle Triassic but the entire area was then uniformly covered by the Schlern Formation. From bottom to top (and from NW to SE) we distinguish three major tectonic units. (1) The Tamar Nappe is characterized by Upper Carnian to Rhaetian carbonates rich in organic matter and chert nodules. (2) The Krn Nappe has the largest areal extent and mainly consists of the Dachstein limestone. Middle Jurassic deposits are cherts and calcareous turbidites or condensed Rosso Ammonitico limestone. (3) The Pokljuka Nappe is composed of deep-water Upper Triassic to Lower Cretaceous deposits. The most distinguishing stratigraphic unit is the Valanginian-Hauterivian flysch-type deposits that suggest a correlation with relatively internal tectonic units of the Northern Calcareous Alps and Dinarides. The Zlatna Klippe in the central part of the Julian Alps is structurally well differentiated but stratigraphically less distinctive, because it is composed only of the Schlern Formation and older rocks. Its position on top of the Krn Nappe suggests that the Zlatna Klippe is part of the Pokljuka Nappe.

The Julian nappes are dissected by parallel reverse faults oblique to the Sava Fault. Fault-propagation folds are the most commonly observed structures along these faults. The NE-SW striking faults east of the Vrata-Trenta line are characterized by SE vergent folds, whereas the folds and the steepened beds west of this line have the same orientation but the opposite vergence. South of Bohinj, i.e. closer to the Tolmin nappes, the faults are NW-SE trending and the associated folds are S to SW vergent. This pattern suggests an overall pop-up structure and CW rotation of internal smaller-scale fault blocks. A number of later normal faults have been observed, with down throw ranging from a few meters to several hundred meters.

The three-stage Paleogene to early Neogene deformation history, generally postulated for the eastern Southern Alps, is well recognized in the Julian Alps. The Dinaric phase was characterized by nappe emplacement, presumably towards west, perpendicularly to the orogen. During the Insubric transpressional phase, doubly-vergent reverse faults and CW rotation of fault blocks characterized the rheologically stiffer Julian nappes. At the same time the entire stack of the Julian nappes may have been transported southward on top of the Tolmin nappes and individual slices of the Tolmin nappes were imbricated. The subsequent short-lasting extensional phase near the end of the Early Miocene caused subsidence along steep normal faults in the Julian nappes and exhumation of the deeply-buried Tolmin nappes.

Magnetic susceptibility and spectral gamma ray stratigraphy of the Tithonian – Berriasian limestones in the Carpathians of Poland and Hungary – paleoenvironmental implications

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